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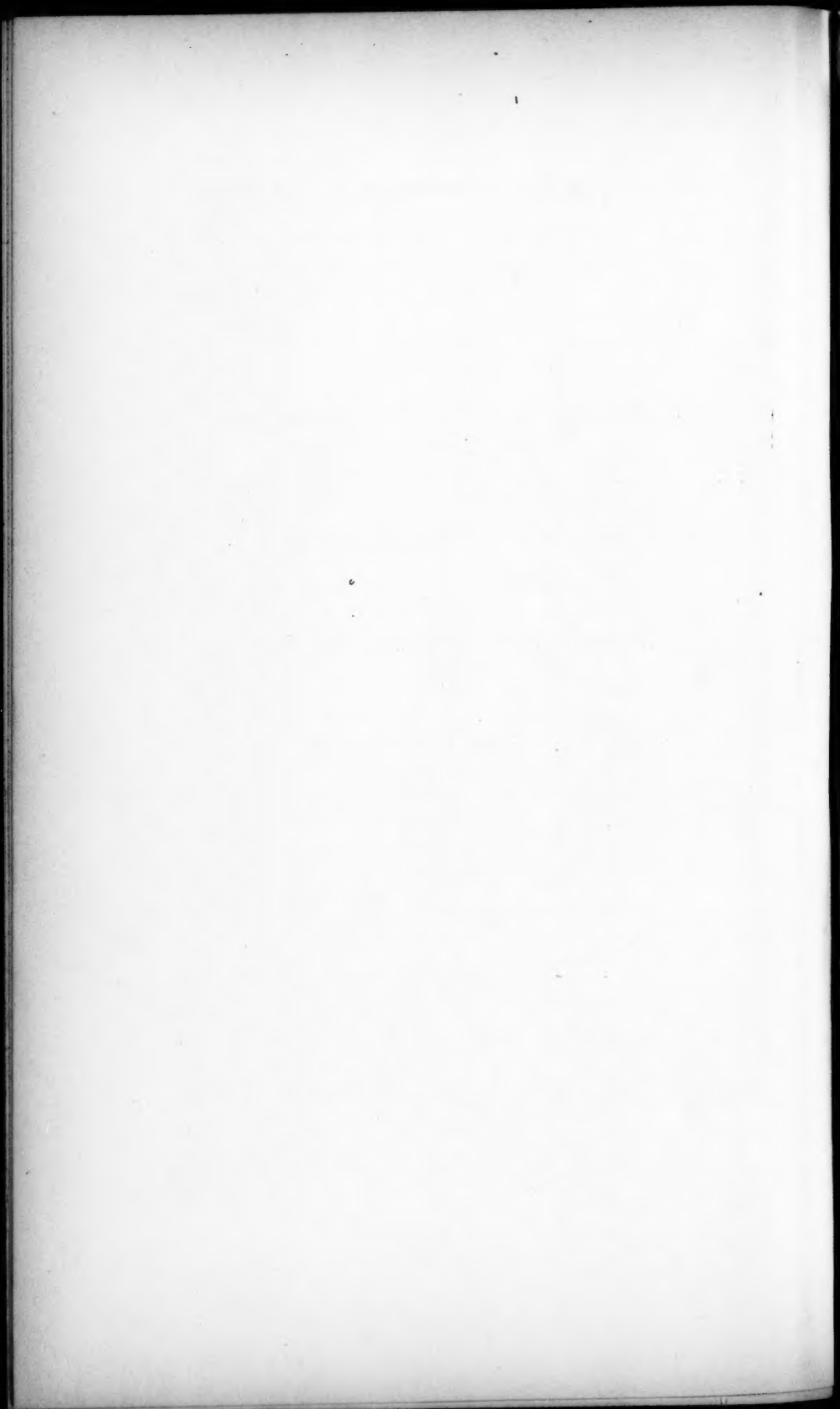
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CONTRIBUTIONS FROM THE HARVARD MINERALOGICAL
MUSEUM. — X.

APATITE FROM MINOT, MAINE.

BY JOHN E. WOLFF AND CHARLES PALACHE.

WITH A PLATE.



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APATITE FROM MINOT, MAINE.

BY JOHN E. WOLFF AND CHARLES PALACHE.

Presented December 11, 1901. Received February 7, 1902.

In the summer of 1901, while prospecting for tourmaline or other gem minerals on the farm of Mr. P. P. Pulsifer in Minot, Maine, a pocket was opened in the granite containing the material here described. It was first brought to our notice by Mr. C. L. Whittle, formerly of this Department, and the whole was subsequently acquired by the Harvard Mineralogical Museum.

This find is noteworthy for the unusually rich purple color of the crystals, and the purity, crystalline perfection, and abundance of the material, which comprises about two thousand loose crystals or fragments of crystals with a total weight of over a kilogramme, and about a dozen large groups of crystals on the matrix. Of the loose crystals about three hundred show at least one perfect termination, five hundred are slightly less perfect, and the rest imperfect or fragmentary.

PARAGENESIS.

The apatite was found in a single cavity in pegmatitic granite, the walls of which appear to have been lined with crystals of quartz, orthoclase, and lepidolite, with which in smaller amounts were albite, muscovite, and cookeite.

The quartz crystals range from small dimensions up to a height and thickness of 15 cm. They show the common quartz forms only, the positive and negative unit rhombohedrons and the prism, and are notable chiefly as presenting in a very striking manner the evidence of two periods of growth. Wherever broken and whether large or small, the crystals show a core of glassy, light to dark smoky quartz; surrounding this is a surface layer of white opaque quartz from 1 to 3 mm. in thickness, crystallographically continuous with the smoky quartz, but on many of the faces, especially those of the rhombohedrons, composed of

a multitude of small parallel crystals which give the surface a pitted appearance.

A thin section cut across this boundary showed under the microscope that the outer opaque layer was in crystallographic continuity with the inner part, but the line between them was sharp, the opaque layer containing very abundant liquid and obscure solid inclusions and showing faintly a division into fibres or columns perpendicular to the surface. The appearance pointed to a second period of quartz deposition rather than to an alteration of quartz previously formed. The evidence of the secondary deposition of the white quartz was rendered stronger by the occurrence in several places between the two layers of a thin deposit, not more than 1 mm. thick, of tiny muscovite crystals, or of a double layer of muscovite and cookeite. The apatite crystals are often deeply embedded in the white quartz and seem to have developed in part *pari passu* with this material; but at no place does the apatite appear to penetrate the smoky quartz.

The lepidolite is in part in confused lamellar aggregates, in part in quite definite hexagonal prismatic crystals with somewhat rounded basal terminations. The interior of these crystals is of the characteristic pale lilac color of lepidolite, but their surfaces are everywhere covered by a uniform layer of pale greenish-white muscovite about 1 mm. in thickness. The cleavage of the lepidolite and of the bordering muscovite is absolutely continuous, but the boundary between them is sharp and plane, showing that the muscovite represents, not an alteration of lepidolite, but a later parallel growth of the new and isomorphic mineral, a sort of secondary enlargement. Sharply bounded lepidolite crystals without the muscovite border are sometimes enclosed in the smoky quartz, showing that these two minerals were of contemporaneous growth.

The orthoclase, a pale flesh-colored variety, and the albite, colorless, in thin plates showing albite twinning, are small in amount, and their relations to the smoky quartz show that they belonged to the same period of growth with it.

Cookeite occurs quite abundantly on some of the specimens as crusts or clumps of scales or platy crystals of a greenish-white color. It is similar in appearance to the muscovite, but is slightly darker in color, less pearly in lustre, and readily distinguished by its reactions before the blowpipe. The cookeite appears to have been formed at several periods of mineral growth in the cavity. It is seen occasionally as above stated in thin layers between the outer white quartz layer and the coating of

muscovite; more frequently it forms an irregular layer on the lepidolite-muscovite crystals, showing, however, no parallelism with them; and it is rarely included in, and in small amount deposited upon, the apatite crystals. In no case does the cookeite appear to have been formed at the expense of any of the minerals previously formed in the cavity, which are perfectly fresh and free from alteration.

The apatite is implanted upon the quartz crystals and upon the lepidolite-muscovite crystals or the cookeite which covers them. As stated above the apatite is embedded at times in the white quartz layer in which it leaves sharp moulds when broken out, it having maintained its crystal form despite the interference of the quartz.

Finally a third generation of quartz in minute crystals is found associated with the cookeite, and rarely implanted upon the apatite crystals.

To briefly recapitulate the facts relating to the paragenesis of this deposit we may say that we find:

First, the crystallization of the smoky quartz, lepidolite, orthoclase, and albite, the normal constituents of the granite, to form the walls of the cavity.

Second, the crystallization of muscovite, coating smoky quartz crystals in part and the lepidolite crystals wholly.

Third, the crystallization of cookeite, coating muscovite, wholly or in part.

Fourth, the simultaneous crystallization of apatite and white quartz, the latter confined to enlargement of smoky quartz crystals.

Fifth, a second period of cookeite formation, accompanied by a final deposition of quartz.

CRYSTALLOGRAPHY.*

The apatite crystals are in general of pronounced prismatic habit, the average size being about 1 cm. in height and 0.5 cm. in diameter. Crystals larger than this are, however, common, the largest measuring nearly 3 cm. in height and diameter. Crystals smaller than the average, which are also numerous, tend to assume a more or less rounded habit by nearly equal development of prismatic and terminal planes.

The crystals are generally so implanted upon a terminal face that one end has developed freely, and the fact that over three hundred loose crystals with complete single termination and prism zone were

* By C. Palache.

obtained from the collection shows how prevailing is this habit of growth. Occasionally the attachment to the matrix is by a prism plane, and then both terminations are developed.

The forms observed were as follows, the letters used being those of Dana:

c (0001), m (10 $\bar{1}$ 0), a (11 $\bar{2}$ 0), h (21 $\bar{3}$ 0), z (30 $\bar{3}$ 1), y (20 $\bar{2}$ 1), x (10 $\bar{1}$ 1), r (10 $\bar{1}$ 2), w (7073), s (11 $\bar{2}$ 1), μ (21 $\bar{3}$ 1), μ_1 (31 $\bar{2}$ 1).

Four crystals were carefully measured on the two-circle goniometer and the same forms found on all. The results of measurement of the better developed forms agreed so well among themselves that it seemed worth while to calculate the axial ratio from the better readings, and this was done, using the forms y , x , r , and s . The following table shows the average angle to the base from each of these, the ratio calculated for each crystal, and the average ratio obtained:

	Angle from 0001 to 20 $\bar{2}$ 1.	No. of Faces.	d.*		Angle from 0001 to 10 $\bar{1}$ 2.	No. of Faces.	d.*
Cryst. 1 . .	59° 29'	5	3'	Cryst. 1 . .	23° 00'	6	1'
" 2 . .	59° 29½'	5	2'	" 2 . .	23° 00'	5	5'
" 3 . .	59° 30¼'	6	3'	" 3 . .	23° 00'	3	0'
" 4 . .	59° 28½'	5	3'	" 4 . .	22° 50¼'	4	3'
	Angle from 0001 to 10 $\bar{1}$ 1.				Angle from 0001 to 11 $\bar{2}$ 1.		
Cryst. 1 . .	40° 18'	6	3'	Cryst. 1 . .	55° 45'	6	1'
" 2 . .	40° 19'	5	5'	" 2 . .	55° 46'	6	3'
" 3 . .	40° 19'	5	6'	" 3 . .	55° 46'	4	3'
" 4 . .	40° 18'	5	2'	" 4 . .	55° 45'	6	4'

Crystal 1, from 23 measurements, $p_0 = 0.848307$

Crystal 2, from 21 measurements, $p_0 = 0.848739$

Crystal 3, from 18 measurements, $p_0 = 0.848753$

Crystal 4, from 20 measurements, $p_0 = 0.848148$

Average from 82 measurements, $p_0 = 0.848476$ or $a : c = 1 : 0.734800$

Angle calculated from $p_0 = 0.848476$, 0001 to 20 $\bar{2}$ 1 59° 29' 22''

0001 to 10 $\bar{1}$ 1 40 18 50

0001 to 10 $\bar{1}$ 2 22 59 19

0001 to 11 $\bar{2}$ 1 55 45 59

Two types of combinations may be distinguished among these crystals. One of these is represented in figure 1, and consists essentially of the

* d is the difference in minutes between largest and smallest readings for faces of any form.

prism of the first order and the base, the edges modified by narrow planes of the forms a , s , r , x , and y . Crystals of this type are not uncommon and often show double terminations. They merge, however, by slight gradations into the second type, more characteristic for the locality, shown in figures 2 and 3. Here the pyramidal planes become more prominent and the most notable feature is the simultaneous occurrence of the right and left third order pyramids, giving the appearance of the normal dihexagonal pyramid.

The different forms may be characterized as follows:

c (0001) always present, generally large, brilliant, and plane giving perfect reflections.

m (10 $\bar{1}$ 0) always present, generally dominant, brilliant, and generally plane but sometimes faintly striated vertically.

a (11 $\bar{2}$ 0) generally present but narrow and commonly dull from deep striation, the striae vertical and bounded by faces of adjoining planes of m . Occasionally the striations stop abruptly in the centre or near the boundaries of a face as shown in figure 3, or they may be wholly lacking, in which case the face is brilliant and gives good reflections.

h (21 $\bar{3}$ 0) rarely developed and then narrow as shown in figure 4. Surface plane, not involved in striations on a .

r (10 $\bar{1}$ 2), x (10 $\bar{1}$ 1), and y (20 $\bar{2}$ 1) all nearly always present with all their faces, in varying proportions and often large, faces always brilliant and free from striations, giving perfect reflections.

w (70 $\bar{7}$ 3) observed but once as a line face in the zone between y and m .

z (30 $\bar{3}$ 1) generally present only as a deeply striated face, sometimes very large as in figure 4, giving no reflection but determined by its zonal relation to μ and μ_1 . The striae bounded by faces parallel to adjoining planes of m and y . Narrow faces of z giving faint reflections sometimes present on the edges of the striae nearest to m .

s (11 $\bar{2}$ 1) always present with brilliant faces, often large.

μ (21 $\bar{3}$ 1) and μ_1 (31 $\bar{2}$ 1) are both present on many crystals, but vary widely in size, quality, and regularity of development. Generally the faces of both are dull and the forms are then indistinguishable. On some crystals their faces are brilliant and reflecting but grooved or pitted, and a constant difference in the character of these markings was found by which, when they were not too far developed, the two forms could be distinguished. On μ the markings ordinarily take the form of sharp grooves parallel to the intersection of m and μ as shown in figures 2 and 3. The grooves seem to be in a way continuations of the striae

on the faces of z , for they never extend beyond the intersection of μ with that face, and are absent if z is not developed. The grooves are bounded by faces parallel to adjacent planes of s and of m . Very often they stop short in the middle of the face as shown in figure 3.

On μ_1 the markings are in the form of irregular pits or curving grooves, sometimes showing approximate parallelism to the intersection of m and μ_1 but with an irregularity giving them a character wholly different from the lines on μ . No constant difference could be observed in the brilliancy of the reflecting portions of faces of the two forms, nor in their relative size. Both are irregular in their occurrence on individual crystals, lacking nearly always some of their faces. As shown in the figures, both may present on the same crystal faces of very unequal size which in some cases are so large as to dominate the termination of the crystal.

The occurrence of third order pyramids in apparently holohedral combination has been observed on apatite from various localities, notably Knappenwand, Tyrol,* Ala, Piedmont,† and El'ba.‡ But in none of the crystals described does there appear to have been any observable difference between the faces of the right and left forms by which they could be distinguished.

Reference has been made in the preceding pages to striations which appear quite constantly on certain faces of the apatite. They are a striking feature of the crystals and the attempt has been made to reproduce them in the drawings. Their most pronounced development was on the largest crystal of the collection, which is reproduced in figure 4; the striations on the faces of z and of a were almost equally strong and gave the crystal a curiously tetragonal aspect when inspected casually. On both of these forms the striations are doubtless growth forms, the result of oscillatory combination, on a of adjacent faces of m , and on z of planes of m and y . The markings on the faces of μ and μ_1 seem to have a different character, however. The irregularity of their development, appearing on some faces as mere grooves or pits, on others invading the whole face and reducing it to a dull surface, indicates that they are rather the result of etching by some agent which has attacked the crystals after they were formed.

* C. Klein, Neues Jahrb. Miner., 1871, 485; 1872, 121.

† G. Struever, Att. Acc. Torino, 3, 125, 1867; 6, 363, 1871; Rendic. R. Acc. Lincei, Roma, 1899, 8 (1), 427-434.

‡ E. Artini, Rendic. R. Acc. Lincei, Roma, 1895, 4 (2), 259.

CHEMICAL COMPOSITION.*

The material for analysis was taken from the deep purple clear crystals, which were broken free from any adhering gangue and carefully examined with the lens; while the microscope confirmed the purity of the mineral. The method followed was essentially that used

	A.	B.	Ratios.		J.
P ₂ O ₅	41.30	41.58	0.2928	0.2928	39.84
(FeAl) ₂ O ₃ . .	0.71	0.71	0.0044	1.0029	{ Al ₂ O ₃ 2.02 FeO 0.62
MnO	0.85	0.86	0.0121		0.22
CaO	53.43	53.79	0.9605		53.36
MgO	0.70	0.70	0.0178		0.25
K ₂ O	0.27	0.27	0.0028		0.52
Na ₂ O	0.36	0.36	0.0058	†0.0323	0.42
H ₂ O	0.29	0.29	0.0028		0.48
Cl	abs.	...	...		1.82
F	2.38	2.40	0.1263	0.1586	1.03
Loss at 320° .	0.04	0.04			
	100.33	101.00			100.58
Less O = F . *	1.00	1.00			0.90
	99.33	100.00			99.68
Sp. gr., 3.159 at 20° C.					

A. Apatite from Minot, Maine.

B. Calculated to 100.

J. Apatite from Ceylon, Jannasch and Locke, loc. cit.

Hence, P₂O₅ : RO : F.OH,

1 : 3.42 : 0.57

1.5 : 5.13 : 0.85

or, Ca₅P₃[F.OH]O₁₂.

* By J. E. Wolff.

† Calculated as OH = 0.55 per cent OH.

by Jannasch and Locke, * namely solution in nitric acid with addition of mercuric oxide, precipitation with ammonia and determination of phosphoric acid, most of the lime and the other bases in the precipitate, while the rest of the lime and the alkalies were determined in the first filtrate. Water was determined directly by fusion with plumbic oxide mixed with potassium di-chromate.

Fluorine was determined by the method of Fresenius, that is by heating the finely powdered mineral, mixed with previously ignited quartz, in a flask with strong sulphuric acid and absorbing the SiF_4 in weighed tubes with the prescribed precautions. From the total weight obtained there was subtracted a correction for the general gain in weight of the absorption tubes due to the action of the air current on the rubber connections; etc., which had been previously determined by experiment. The process was continued for five hours or to a constant weight. Chlorine was absent.

The mineral was soluble without residue in nitric acid. At about 320°C ., the purple color disappears and the mineral becomes colorless or faintly yellow; this change is accompanied by some decrepitation, by phosphorence, and the production of a vapor (in part water?) which is deposited in drops on the walls of the tube; there is also a petroleum-like odor. The loss of weight accompanying this change was determined by gently heating three grammes of the mineral in a bulb tube in a current of dry air, weighing, and heating again cautiously in the current of air to complete decolorization, and determining the loss of weight.

OPTICAL PROPERTIES.†

For the determination of the indices of refraction one of the best clear crystals was used, having a deep purple color and a brilliant basal plane. The determination was made with the Abbé crystal refractometer by the differential method ‡ and for this purpose a glass prism was selected having the index $n_{\text{Na}} = 1.6326$, for which the boundary of total reflection was carefully determined and the telescope clamped. The apatite crystal was then placed with its base on the glass hemisphere of the apparatus and the angular difference in the boundaries for ω and ϵ determined by the millimeter screw reading to six seconds. The boun-

* Zeit. anorg. Chemie, 7, p. 154; also Jannasch, Praktischer Leitfaden d. Gewichts Analyse, p. 259.

† By J. E. Wolff.

‡ C. Viola, Zeit. Krystall., 30, p. 438, and 32, p. 311.

dary lines were sharp and the readings generally good. From the average of a large number of readings the following values were obtained :

$$\begin{array}{lll} \omega_{Na} = 1.63353 & \omega_{Li} = 1.63067 & \\ \epsilon_{Na} = 1.63162 & \epsilon_{Li} = 1.62865 & \end{array}$$

$$\omega - \epsilon = 0.00191 \qquad \omega - \epsilon = 0.0020$$

The crystal was then heated to 320° C. or until decolorized and the indices again determined as follows :

$$\omega_{Na} = 1.63346 \qquad \epsilon_{Na} = 1.63165 \qquad \omega - \epsilon = 0.00181$$

The change in the bi-refringence and in both indices is within the limits of error.

The pleochroism is strong and the ray vibrating parallel to \hat{c} (ϵ) red-dish purple, perpendicular to \hat{c} (ω) deep violet blue. In converging light the thick clear crystals show on the basal plane a marked bi-axial character with the vertical axis the acute (negative) bisectrix and a division of the base into six sectors, in each of which the axial plane is parallel to a prism of the second order (or perpendicular to a lateral axis). These sectors come out clearly with the sensitive tint of the gypsum plate; while some are almost perfect, others merge together and overlap at the centre of the crystal. The angle of the optic axes in one of these sectors was measured in the optic angle apparatus :

$$2E_{Na} = 20^\circ,$$

but it appears to vary in different sectors of the same crystal. These phenomena of apparent orthorhombic symmetry were described and figured by Mallard* for the violet apatite from Schlaggenwald, but appear to be even more distinct in the Maine apatite. While driving off the coloring matter destroys the pleochroism the anomalous bi-axial characters are not affected.

CONCLUSION.

The Minot apatite is a pure fluor-apatite with a fluorine content lower than that necessary for the formula $Ca_5F(PO_4)_3$ and indicating Groth's formula $Ca_5P_3(F.OH)O_{12}$ as also deduced by Jannasch from the analysis quoted above. Rammelsberg† explained the low content of fluorine (and chlorine) in certain apatites as due to removal of these elements

* Annales des Mines, VII. 10, 1876, p. 147.

† N. J. M., 1897, 2, p. 38.

by a process of alteration, and therefore, according to him, all such apatites are altered. The freshness of the Minot material makes such a supposition inapplicable here.

The axial ratio of the Minot apatite is the largest and the birefringence the lowest recorded for the species. It was interesting to see what data existed for a comparison between fluorine or chlorine content and the axial ratio, specific gravity, and birefringence.

The normal angle c to x and also the specific gravity of apatite have been held by numerous observers to diminish with increasing chlorine content.

G. Rose (Ref. 3 below), the first to discover the fluorine and chlorine in apatite, stated as the result of his studies that the angles and specific gravity were alike in all apatites of like composition, but that the reverse of this statement was not proved.

Von Kokscharow (Ref. 2) extended this statement, holding that the normal angle c to x of all chlorine-containing apatite was somewhat less than that of pure fluor-apatite.

The analyses of Pusyrewsky (Ref. 18) seemed to confirm this view, and he further maintained that the specific gravity regularly decreased with increasing chlorine.

Von Kokscharow (*loc. cit.*) incorporated the results of the last writer with his measurements and published a table showing the relations of the three values, but without comment.

Baumhauer (Ref. 4) was the next to investigate the subject, and his measurements, analyses, and specific gravity determinations seemed to support the supposed relations. His table has been republished by several authors with slight modifications (Dana, *Syst.*, 1892, 764, and Weibull, Ref. 20 below).*

In order more fully to test the matter a table has been prepared and is given below, arranged according to increasing values of the angle c to x or of the axial ratio, and showing for all occurrences for which accurate crystallographic data existed, the specific gravity, birefringence, and chlorine and fluorine content so far as such data could be found.

* In Baumhauer's table and in all later tables of the same kind the locality Schlaggenwald is given with c to x $40^{\circ} 20'$, the largest value for this angle observed on apatite. Reference to the description of this occurrence by Schrauf (Ref. 8 below) showed that the measured crystals were poorly adapted to measurement, having curved faces; and the average axial ratio calculated from all the measurements gave a value much lower, about $40^{\circ} 17'$. This locality was therefore omitted from the table below.

TABLE OF PHYSICAL AND CHEMICAL CHARACTERS OF APATITE.

Locality	Angle 0001 to 1011	c	Sp. Gr.	ω-e	Cl	F	Ref.
1 Comba di Compare } Robert, Piedmont }	40 4	0.7284	...	...	...	...	1
2 Achmatowsk . . .	40 6 21	0.7294	3.120	...	0.51	...	2 & 18
3 Laacher See . . .	40 6 21	0.7294	3.202	...	...	...	3
4 Rothenkopf, Tirol .	40 10 46	0.7313	3.1495	...	0.085	...	4
5 { Zillerthal, Tirol	...	...	...	...	absent	1.54	5
5 { " "	...	...	...	.00435	...	...	6
6 Tirol . . . . .	...	...	...	.0044	...	...	7
7 Ala, Piedmont . . .	40 10 46	0.7313	...	...	...	...	4
8 Kirjabinsk	40 13 30	0.7325	3.126	...	trace	...	2
Jumilla, Spain . . .	40 11 48	0.7318	...	...	...	...	8
" "	40 13 37	0.7326	3.235	...	0.557	...	2
9 { " " . . . . .	...	...	...	.00448	...	...	9
9 { " " . . . . .	...	...	...	.0042	...	...	19
9 { " " . . . . .	...	...	...	...	0.24	1.98	5
9 { " " . . . . .	...	...	...	...	0.47	3.54	10
10 { Knappenwand, Tirol	40 15 26	0.7333	3.153	...	0.028	...	4
10 { " " . . . . .	...	...	...	...	0.08	3.63	10
11 Tirol (tale schist) .	...	...	...	...	0.20	3.58	10
12 Sulzbachthal, Tirol .	...	...	...	.0026	...	...	7
13 Berg Blagodat . . .	40 16 10	0.7337	{ 3.132 3.200	...	0.21	...	2
14 Nordmarken	40 16 10	0.7337	...	...	...	...	11
15 { St. Gotthard . . .	40 17	0.7340	3.197	...	0.028	...	2 & 3
15 { " "	40 17	0.7340	3.2154	...	...	...	4
16 Tavetsch	40 17	0.7340	...	...	...	...	12
17 Floitenthal	40 17	0.7340	...	...	...	...	12
18 Schwarzenstein . . .	40 17	0.7340	...	...	trace	...	4
19 Vestanå (Mn. apatite)	40 17 20	0.7341	3.225	.0042	trace	3.74	20
20 Hiddenite Mine, N. C.	40 17 45	0.7343	...	...	...	...	13
21 Turkistan	40 18 10	0.7345	3.199	...	trace	3.64	14
22 Tokowaja, Urals . .	40 18 22	0.7346	{ 3.201 3.212	...	0.01	4.20	2 & 18
23 { Ehrenfriedersdorf	40 18 22	0.7346	3.211	...	absent	...	3
23 { " " . . . . .	...	...	...	...	absent	2.27	5
24 Pisek	40 18 25	0.7346	3.094	...	trace	3.56	15
25 Elba	40 18 48	0.7348	...	...	...	...	16
26 Minot, Me.	40 18 50	0.7348	3.159	.0020	absent	2.38	
27 Zwiesel (Mn. apatite)	...	...	3.169	...	absent	2.15	17
28 Ilmen Mts. . . . .	...	...	3.216	...	trace	3.97	18
29 Sudjanka River . . .	...	...	3.178	...	0.109	4.02	18

1 G. Boeris, Atti. della R. Acc. Sc. di Torino, **34**, 609, 1899.

2 Kokscharow, Mat. zu Min. Russ., V. 86, 1866.

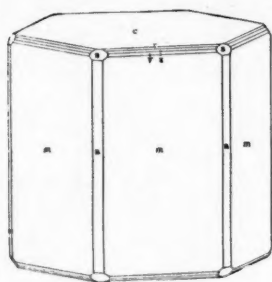
- 3 G. Rose, Pogg. Ann., IX, 206, 1827.
- 4 H. Baumhauer, Zeit. f. Kryst., **18**, 31, 1890.
- 5 Hoskyns-Abraham (Inaug. Diss. 1889), Abs. Zeit. f. Kryst., **21**, 389.
- 6 Heusser, Pogg. Ann., **87**, 468, 1854.
- 7 K. Zimányi, Zeit. f. Kryst., **22**, 331, 1893.
- 8 Schrauf, Ber. Acad. Wien, **62** (2), 745, 1870.
- 9 " " " " **42**, 111, 1862.
- 10 Carnot, Bull. Soc. Franc. Mineral., **19**, 135, 1896.
- 11 Flink, Bihang t. K. Sv. Vet. Akad. H. Stockholm, **12** (2) No. 2, 42, 1886.
- 12 Schmidt, Zeit. f. Kryst., **7**, 551, 1883.
- 13 Hidden & Washington, Zeit. f. Kryst., **14**, 299, 1888.
- 14 Jeremejew & Nikolajew, Zeit. f. Kryst., **11**, 389, 1886.
- 15 Vrba, Zeit. f. Kryst., **15**, 464, 1889.
- 16 Artini, Rendic. R. Acc. Lincei, Roma, **4** (2), 259, 1895.
- 17 Sandberger (Hilger), N. J. Min. 1885, **1**, 171.
- 18 Pusyrewsky, Verh. k. k. Mineral. Gesell. St. Petersburg, 1859-1860 (cited by Baumhauer, No. 4 above).
- 19 Latterman, Rosenbusch, Mik. Phys., **1**, 409, 1892.
- 20 { Weibull, Geöl. För. Forh., Stockholm, **20**, 63, 1898.
- { " " " " " **8**, 492, 1886.

One point brought out by the preparation of this table is the lack of studies of apatite in which on the same material all these characters have been determined. It is also to be noted that no crystallographic data whatever appear to have been secured on what could fairly be called a chlor-apatite, the highest chlorine content in the table being about 0.5 per cent only. Without such data it does not seem that the theory of Pusyrewsky and Baumhauer that axial ratio decreases with chlorine content can be considered as established. Moreover exceptions to that rule may be noted in the table, notably Nos. 5, Zillerthal, and 9, Jumilla. On the other hand it seems fairly safe to accept the statement that an apatite with large angle c to x ($40^\circ 17'$ or more) will be practically free from chlorine.

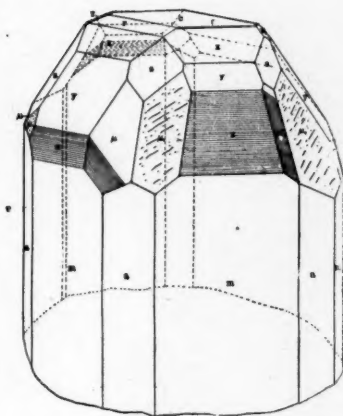
The table shows that absolutely no definite relation exists between the specific gravity and the chlorine content. Nos. 2 and 9, from Achmatowsk and Jumilla, having about 0.5 per cent chlorine, have specific gravity respectively 3.12 and 3.235; while the chlorine-free varieties have specific gravities from 3.09 to 3.22, or practically the same range. Observations on the birefringence are few, but so far as they go do not point to a definite relation to the chlorine content.

HARVARD MINERALOGICAL LABORATORY,
December, 1901.

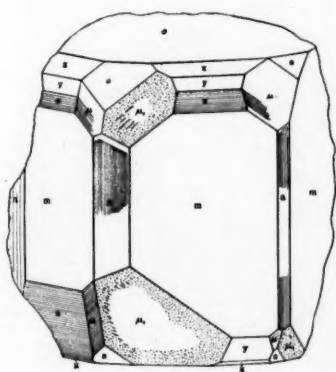
Wolff and Palache. — Apatite.



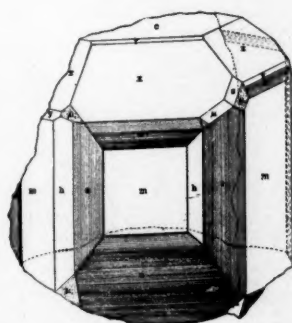
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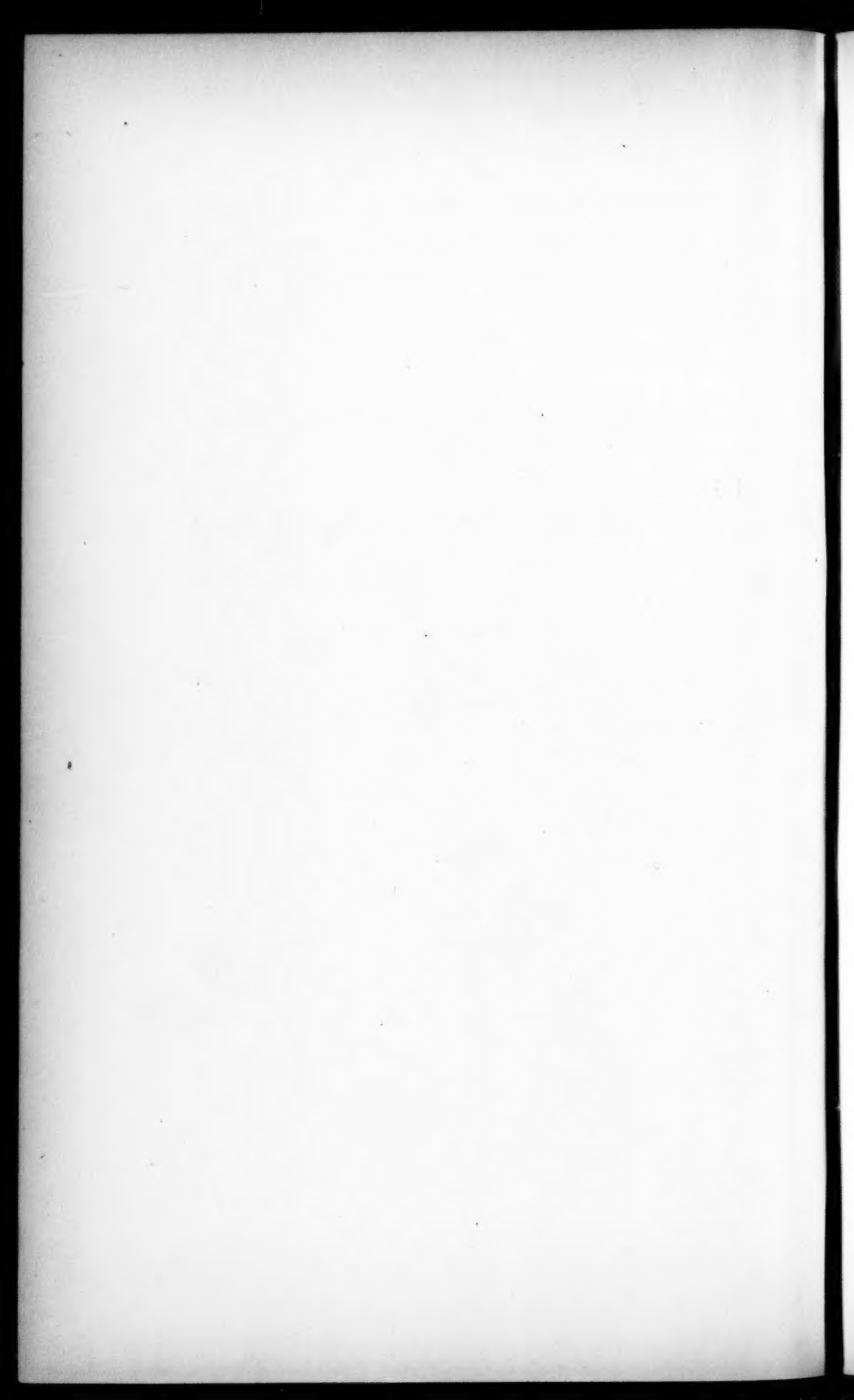
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CONTRIBUTIONS FROM THE HARVARD MINERALOGICAL
MUSEUM.—XI.

A DESCRIPTION OF EPIDOTE CRYSTALS FROM
ALASKA.

BY CHARLES PALACHE.

Presented by John E. Wolff, January 8, 1902. Received February 7, 1902.

THE epidote crystals described in this paper were sent to the Harvard Mineralogical Laboratory for crystallographic study by Mr. W. C. Hart of Manitou, Colorado, to whom we wish to express our thanks for the generous supply of material placed at our disposal.

This material is from a new locality for the mineral and is remarkable for the size and unusual habit of the crystals; it therefore seemed well worthy of description.

According to Mr. Hart the epidote is found at Sulzer, Prince of Wales Island, Alaska. It is in the close vicinity of a body of copper ore and is further associated with garnet, albite, magnetite, and quartz. The country rock of the region is limestone, which is cut by numerous igneous dykes, and it seems probable that the deposit is the result of contact metamorphism of the limestone by the dyke rocks, resembling closely in this respect the epidote occurrence with copper ore in the Seven Devils Mts. in Idaho.*

The specimens at hand consist of several loose crystals and a magnificent cluster of large crystals implanted on massive epidote. The only associated mineral is quartz in small clear crystals of later formation than the epidote.

The epidote is very dark green to greenish black in color, but oil-green and translucent in thin crystals or where bruised or cracked. The larger crystals are in the form of nearly square tables, which measure as much as 5.5 cm. each way and 3 cm. in thickness. In the smaller crystals the tabular habit is less pronounced and the mineral sometimes assumes the ordinary prismatic habit parallel to the \bar{b} axis. The crystals are not

* Compare Am. J. Science, VIII, 1899, 299.

infrequently doubly terminated. In the large group to which reference was made about twenty of the tabular crystals are found on a surface measuring about 15 by 20 cm., several of the crystals over 3 cm. on an edge, and attached by an edge in such fashion as to present an appearance altogether foreign to epidote. The crystals are frequently twinned according to the ordinary law for epidote, twinning plane the orthopinacoid.

Measurement of numerous crystals proved the presence of some twenty-six forms as shown in the following list. The smaller crystals were measured on the two-circle goniometer and most of the faces gave excellent reflections. For the large crystals contact measurements were used, and these, with a study of zonal relations made determinations of forms fairly certain. A few forms were thus found that were not observed on the smaller crystals. Two forms new for epidote are marked with an asterisk.

c (001), b (010), a (100), u (210), z (110), o (011), e (101),
i (102), N (304), r (101), l (201), n (111), α (212), F (454),
Z (232), Φ (353), φ (121), δ (141), E (151), q (221), O (544),*
j (755),* X (322), y (211), R (411), Ψ (413).

Of these forms *c*, *a*, *b*, *u*, *r*, and *n* are nearly always present and define the habit of most crystals. *z*, *e*, *o*, and *q* are also found on many crystals; the remaining forms are rare and subordinate in development. The forms may be characterized as follows:

- c* (001) always present, bright and unstriated, often broad.
- b* (010) always present, always dull and striated parallel to intersection with *n*; generally has narrow faces.
- a* (100) always present; the largest face on tabular crystals; bright but often striated faintly horizontally.
- u* (210) always present, generally with large bright faces.
- z* (110) generally quite subordinate to *u* but frequently present as a narrow face and always pitted and dull.
- o* (011) bright face, generally small.
- e* (101), *i* (102), *N* (304), *l* (201) are infrequent forms in orthodome zone, generally narrow, bright and unstriated when they do occur. This zone is remarkably poor in forms and free from striation as compared with most crystals of epidote.
- r* (101) always present, broad, generally striated lightly and less brilliant than *c* with which it is easily confused on the crystals.

n (I11) always present, often large, brilliant, and striated. The only form found in the re-entrant angles rarely found on twin crystals.

a ($\bar{2}12$) present on one crystal only (figure 7) as a large, fairly bright face.

F ($\bar{4}54$), Z ($\bar{2}32$), Φ ($\bar{3}53$), ϕ (I21), δ (I41), and E (I51) are pyramids of the zone [I11 to 010]. Unimportant forms but several of them sometimes present on single crystals as shown in the drawings. F ($\bar{4}54$), a rare form for epidote, has been reported heretofore only from Persberg, Sweden* by Flink; he determined it by a single bright face in two zones, no angles being given. It was found with a single face on each of two crystals and was measured as follows:

	Measured.		Quality.	Calculated.	
	ϕ	ρ		ϕ	ρ
454	$-160^{\circ} 40'$	$67^{\circ} 21'$	fair	$-160^{\circ} 43'$	$67^{\circ} 18'$ (010 as pole)
	$128^{\circ} 01'$	$29^{\circ} 33'$	fair	$128^{\circ} 18'$	$29^{\circ} 27'$ (normal position)

Φ and δ were determined solely by contact measurements; Z and ϕ by contact measurements and zonal relations.

q ($\bar{2}21$) often present, sometimes large, always dull.

O ($\bar{5}44$), j ($\bar{7}55$), X ($\bar{3}22$), y ($\bar{2}11$), and R ($\bar{4}11$) are pyramids of the zone [I11 to 100]. Of these forms y alone is common; O and j are new to epidote and X and R are rare.

O was measured on three crystals (two of them twins) with six faces as follows:

	Measured.		Quality.	Calculated (010 as pole).	
544	ϕ	ρ		ϕ	ρ
Crystal No. 4,	$-42^{\circ} 04'$	$38^{\circ} 30'$	poor	$42^{\circ} 07'$	$39^{\circ} 33'$
" " 5,	$42 57$	$39 11$	fair	$42 07$	$39 33$
	$137 06$	$38 58$	fair	$137 53$	$39 33$
" " 6,	$-42 13$	$39 20$	good	$-42 07$	$39 33$
	$-137 37$	$39 19$	good	$-137 53$	$39 33$
	$136 48$	$39 18$	fair	$137 53$	$39 33$
Average $-\phi' = +\phi$ or $180^{\circ} - \phi$	$-42^{\circ} 07'$	$39^{\circ} 33'$		$-42^{\circ} 37'$	$39^{\circ} 06'$

The agreement of measured and calculated angles is not very close, but the form seems assured.

j was measured on two twin crystals with three faces as follows:

* Bihang t. K. Sv. Vet. Akad. H. Stockholm, 12, No. 2, 1886.

755	Measured.		Quality.	Calculated.	
	ϕ	ρ		ϕ	ρ
	37° 41'	42° 17'	fair	37° 40'	42° 11'
	142 07	41 44	poor	142 20	42 11
	143 16	42 42	bad	142 07	42 11
Average ϕ or $180^\circ - \phi = 37^\circ 26'$				37° 40'	42° 11'

The agreement between measured and calculated angles is here fairly satisfactory and the form seems assured.

X (322) has been reported only once on epidote from Elba by A. Artini * who measured a single bright face agreeing well with its calculated angle.

It was found here on a single crystal with one measurable face, but was noted frequently as a dull face in the zone [221 to 101].

322	Measured		Calculated (010 as pole)	
	ϕ	ρ	ϕ	ρ
	142° 00'	66° 08'	141° 47'	66° 20'

y (211) and R (411) were the commonest forms of this series and were well determined by measurement on several crystals.

Ψ (413) present only on one crystal (figure 7) as a small face.

Several of the above forms are lacking in the Winkeltabellen of Goldschmidt, and as the various values there given have been calculated for each of them they are given in the following table, which also includes two forms for which certain values were found to be incorrectly stated in the Tabellen:

No	Letter Symb.	ϕ	ρ	ξ_0	η_0	ξ	η	x'	y'	d'
		°	°	°	°	°	°			
†54	Φ	353	...	...	...	...	67 34	...	...	...
†79	Ψ	413	53 34	53 31	50 27	31 02	46 04	20 58	I.2113	0.6019 1.3525
83	F	454	19 17	67 18	38 18	66 06	17 44	60 33	0.7897	2.2570 2.3914
84	O	544	31 29	64 43	47 53	61 01	28 11	50 27	I.1060	1.8057 2.1176
85	j	755	35 39	65 46	52 20	61 01	32 07	47 49	I.2955	1.8057 2.2224
86	X	322	38 13	66 29	54 53	61 01	34 34	46 05	I.4220	1.8057 2.2983

The drawings show the extremely variable habit of the crystals.

Figure 1 represents perhaps the commonest type, a tabular twin crystal, the two individuals entirely symmetrical to the twinning plane

* Mem. Acad. Lincei. 4, 380, 1887.

† Correction, Winkeltabellen, p. 130, line 32 from above, col. 10.

‡ Correction, Winkeltabellen, p. 131, line 12 from above, whole line.

and so developed as to present no re-entrant angles. Here as in all the twin crystals the reversal of direction of the striations on 010 in the twinned crystal is the easiest means of recognizing the composite nature of the group.

Figures 2 and 2a are orthographic projections of the same crystal on the orthopinacoid and the clinopinacoid respectively. They represent the largest crystal studied in natural size, and show how irregularly the two twinned crystals are sometimes united — in this case an imperfect penetration having taken place. The upper surface of this crystal is bounded by cleavage planes parallel to c where the crystal was broken from its matrix.

The remaining figures (3 to 7) are orthographic projections on the clinopinacoid.

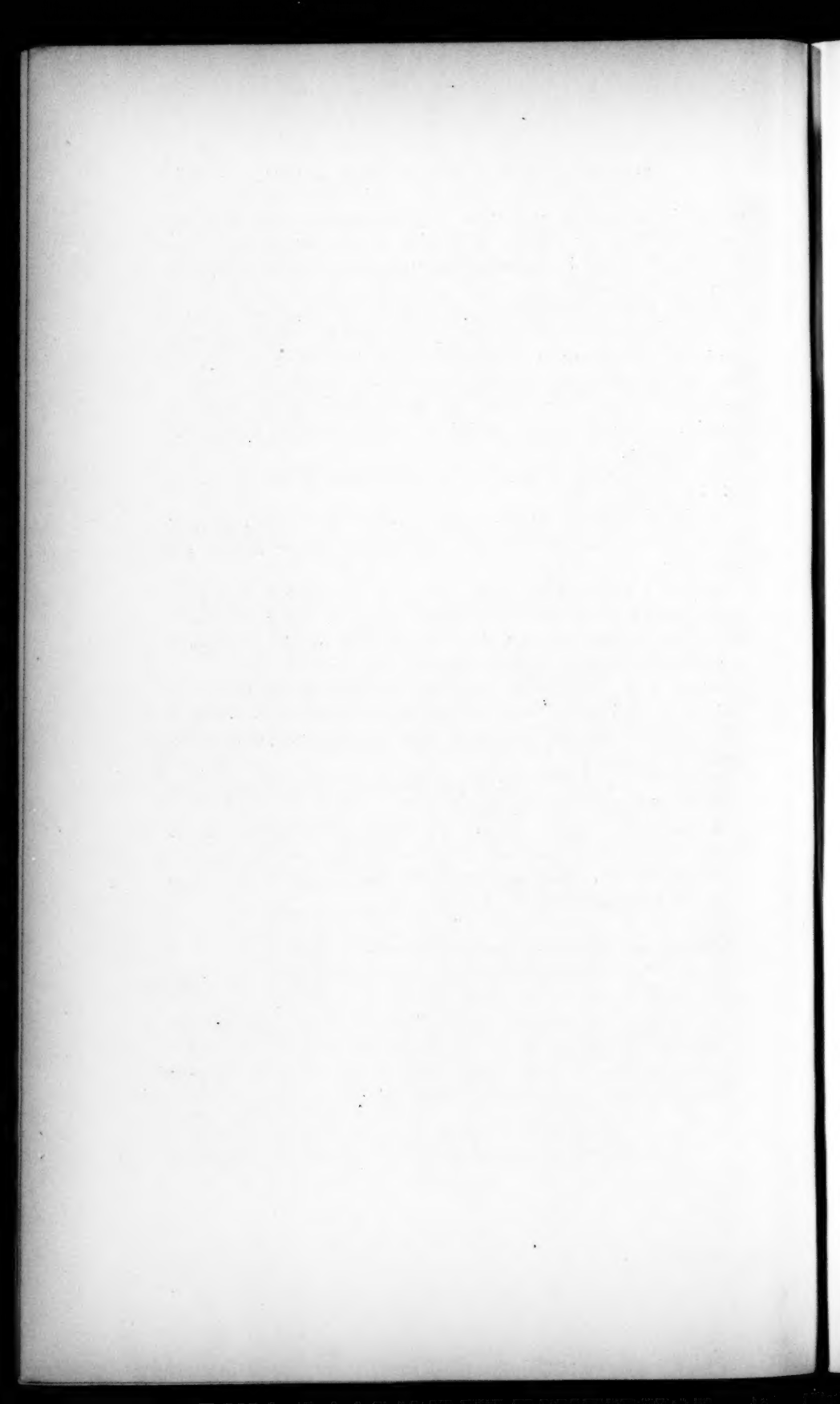
Figure 3 is another tabular crystal in which the larger portion of the crystal is a single individual. Rarely such tabular crystals are untwinned.

Figures 4 and 5 are two very symmetrical twin crystals, both prismatic parallel to the axis \bar{b} and doubly terminated. They show many of the less common forms and the re-entrant angle between two faces of n which is not common on these crystals.

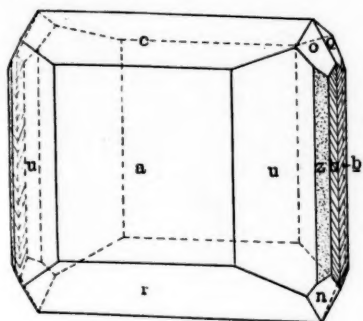
Figure 6 is a type of the untwinned crystal, prismatic parallel to axis \bar{b} , the usual epidote habit. It is a left-hand termination. Many of the smaller crystals are of this habit with varying development of the planes of n and u .

Figure 7 is a small crystal of prismatic habit but quite unlike any other found in its terminal planes.

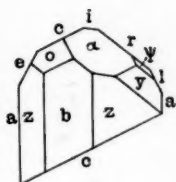
In conclusion it may be said that this Alaska epidote ranks among the finest occurrences of American crystallized minerals, and is only surpassed in the size, beauty, and complexity of its crystals by the epidote from the Knappenwand in the Tyrol.



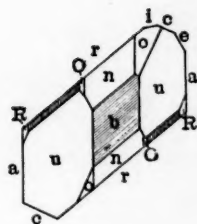
Palache. — Epidote Crystals.



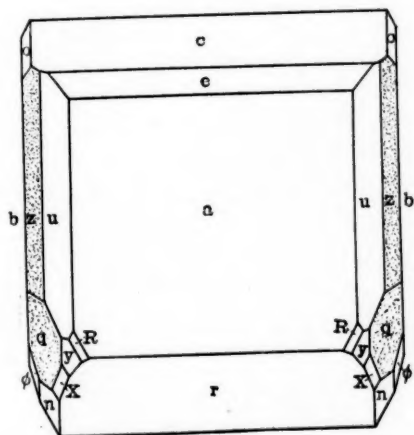
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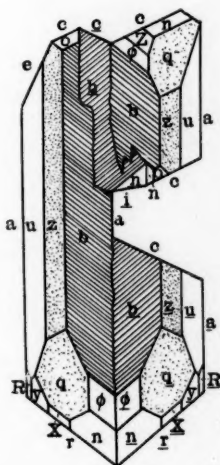
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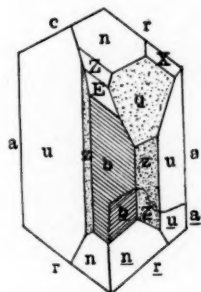
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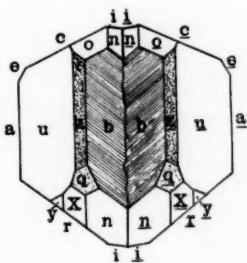
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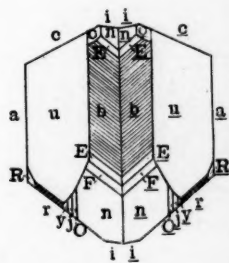
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